Power Distribution using Rad-Tol Regulators

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Problems with existing scheme:

- Describe limitations and concerns for baseline scheme
- Information on transient protection
- Adoption of 0.25μ baseline for electronics on pixel module increases concern about the existing scheme.

Proposal to place individual regulators at PP2:

- Features of CERN/ST Rad-Tol regulator
- Implementation for pixels inside PP2 region
- Advantages/Disadvantages
- Services implications
- Prototype plans

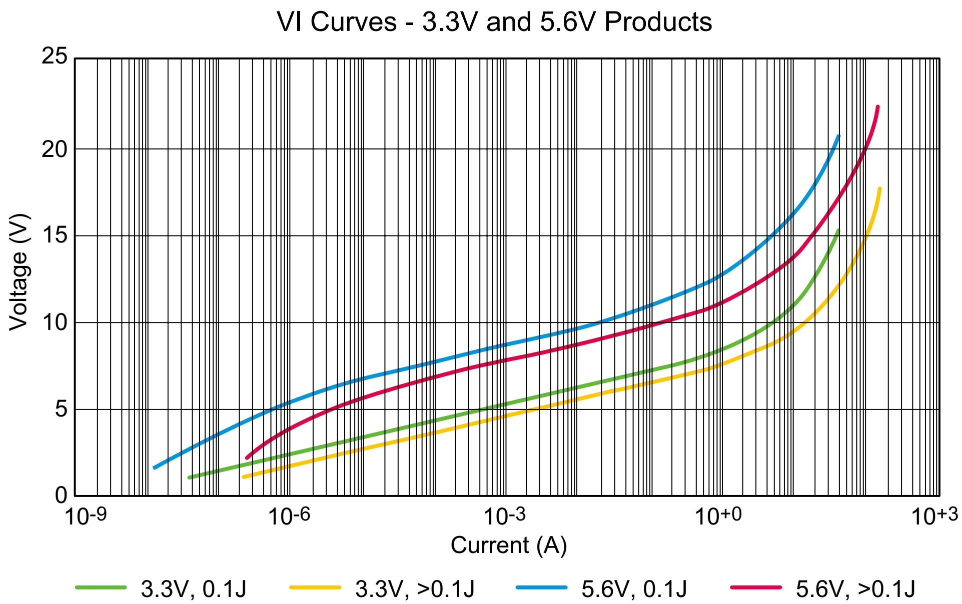
Problems and concerns with existing scheme:

- Very large separation between regulation in USA15 supplies and pixel detector (up to 140m). This makes it difficult to eliminate noise on the power supply lines (active regulation is much more effective than passive filtering), and difficult to control transients induced by changes in current through the high-voltage-drop cable plant.
- For DMILL, the power cables were specified to have a voltage drop (round-trip) of not much more than 2V. In combination with the worst-case supply voltage on the chip of 4V, this still kept the supply voltage itself below the breakdown voltage of the process (about 8V). For 0.25μ, this is no longer possible, because the operating voltage is 2V and the breakdown voltage about 4V. Different transient protection schemes are under study (they must be very rad-hard) to protect the chips against anomalous voltages on the power cables, but margin is very small.
- The inner part of the cable plant (PP2 and in) has almost 1.5V drop round-trip, so designing a total voltage drop of 2V requires very large cables for the long conventional run (Type 4), leading to very high costs, dominated by Copper.
- The large voltage drops in the low-mass cable plant cause significant cooling problems, and make it difficult to know the temperature of the cables, and hence their resistance. This makes it difficult to predict the voltage delivered to a module. The 140m total cable length is too long to operate a standard voltage sensing scheme, so the regulation is based on current sensing, and requires programming a value for the cable resistance into each supply channel.

More on Transient Protection

AVX Varistor transient protection:

- Devices of choice seem to be TransGuard product from AVX. These are varistors, ceramic semiconductors based on ZnO. They operate like a pair of back-back Zener diodes, but have a "distributed" junction to provide much better current and energy absorption than Zeners.
- They will switch on in less than 1 ns, but do not have a terribly steep I/V curve. The lowest voltage part is 3.3V. It has a "breakdown" voltage of 4-6V (voltage at which I = 1mA), and an equivalent R less than 1Ω at about 8V:

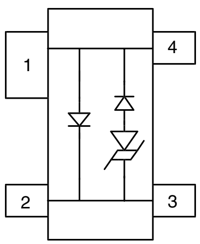


- Part of interest is 3.3V 0.3J 0805 component.

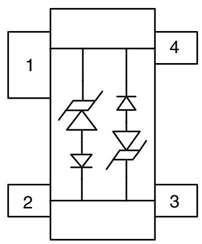
SemTech TVS Diode:

- Semiconductor part, based on “enhanced punch-through” diode. It uses a complex pnnp structure in which avalanche behavior under reverse bias is suppressed and punch-through conduction is enhanced above threshold voltage.

Circuit Diagrams

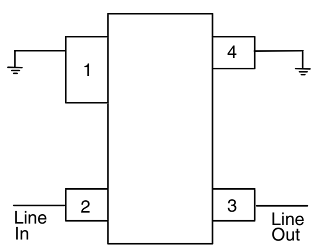


SLVG2.8



SLVE2.8

Connection Diagrams



Common Mode Protection
(SLVE2.8 or SLVG2.8)

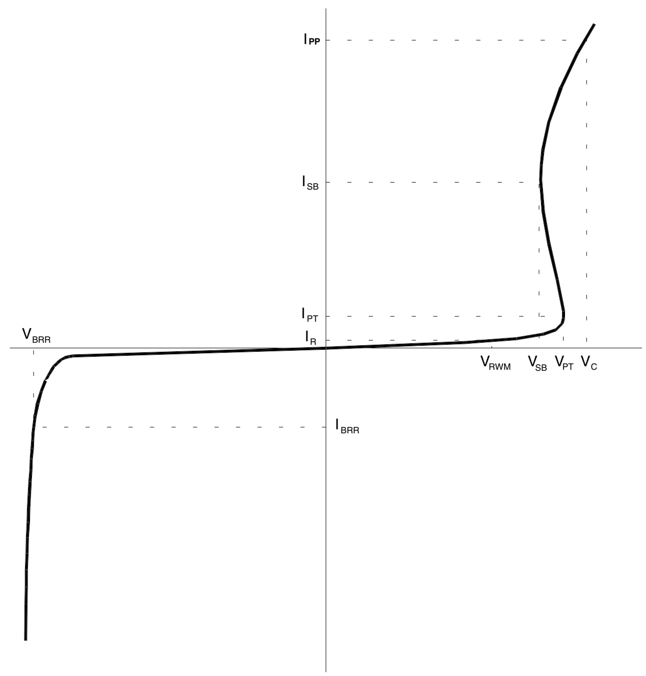


Figure 3 - EPD TVS IV Characteristic Curve

VStandOff
(VRWM) = 2.8V

Vpunchthrough
(VPT) = 3.0V

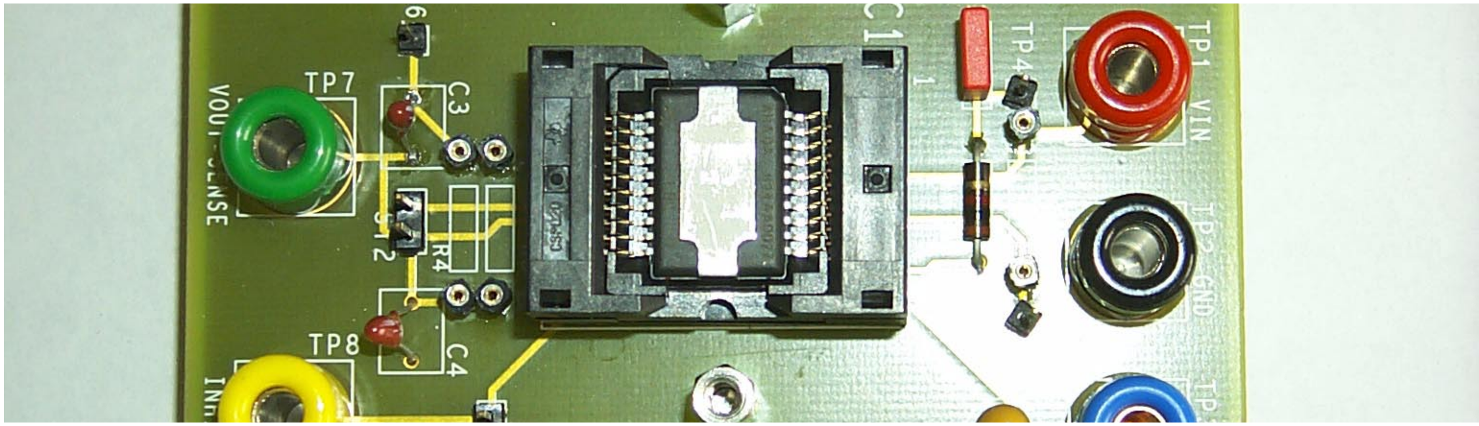
Vsnapback
(VSB) = 2.8V

VClamp
(VC)= 4.1V
for 1A current pulse

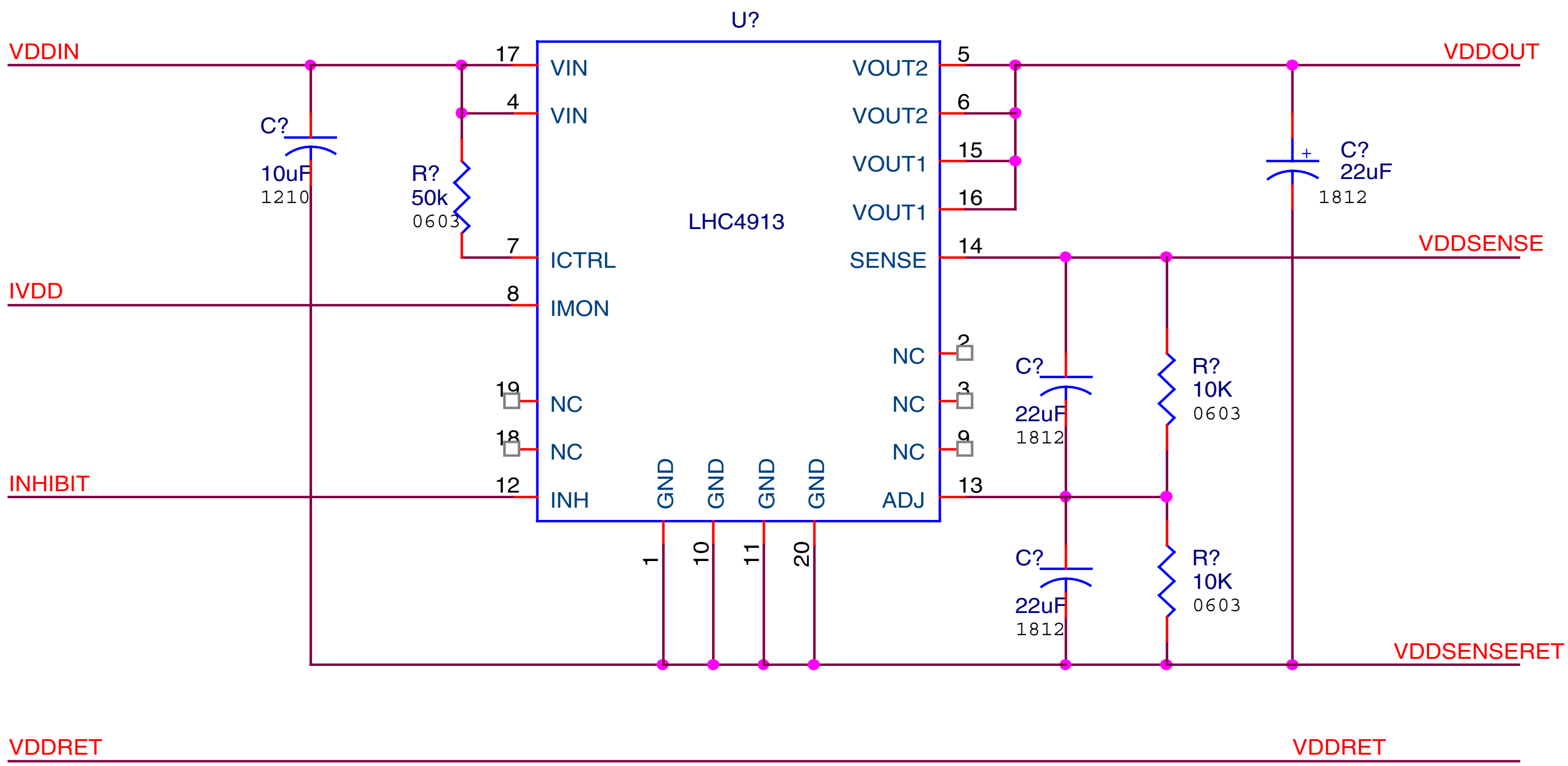
- Packaged as an SOT-143 package, about the same size as a 1210 capacitor.
- Problem for power protection: requires power cycling to restore off-state ?

Proposal to place Rad-Tol regulators at PP2:

- CERN and ST have jointly developed a radiation tolerant regulator using a special bipolar process from ST. It is a high-speed, rad-hard 12V process. The foundry has characterized the process to 0.5MRad and 2×10^{13} n/cm^2. First irradiations show operation is OK up to 10MRad and 3×10^{14} π/cm^2.
- The part, officially called LH4913, is available in several fixed voltages, and an adjustable voltage version (which is best matched to pixel needs).
- The regulator is a low-dropout design, requiring about 0.5V at 1A and 1.5V at 3A. This makes it a good match to pixel modules (worst-case 1.3A per supply).
- It supports a remote sensing mode, includes an inhibit input, has an adjustable maximum current, and includes an over-current status output, plus over-voltage and over-temperature protection circuitry.
- It is packaged in an ST package known as Power-SO20, with a footprint of about 16mm long by 15mm wide, and a slug on the top for heatsink cooling:



Schematic appropriate for use at PP2:



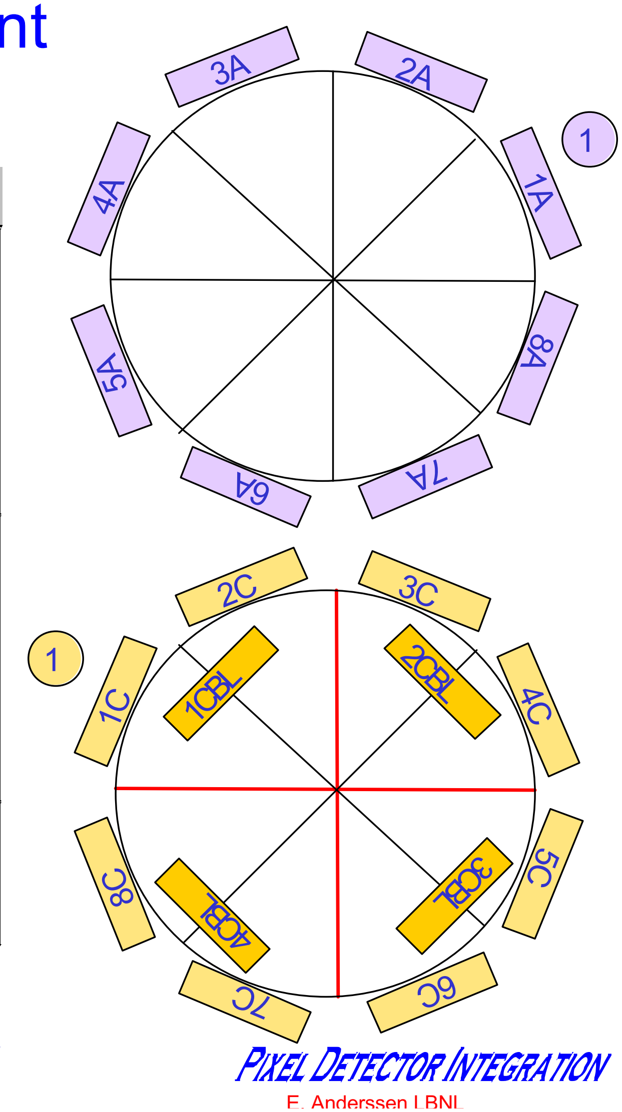
- 50K resistor on ICTRL limits current output to about 1.5A.
- Filtering on input, adjustment nodes, and output is needed. Actual values might be reduced in future versions of regulator. Assume these values based on CERN prototypes. Component sizes (10V X5R ceramic caps) are given in schematic.
- With resistors shown, output voltage would be 2.5V. Varying this voltage requires adjusting the upper of the two 10K resistors. Zero ohms gives minimum of 1.25V.

PP2 Feasibility Study

- Summary of PP2 numerology:

Service Arrangement

	Patch Panel Octant Name	Barrel Layers 1&2	Disk	Tube Total	6-Module Bundle	7-Module Bundles	Bundle Total	Staves Serviced	Sectors Serviced
Side A	1A	3	2	5	(3+6)=9	6	15	12	3
	2A	3	1	4	(3+6)=9	6	15	12	3
	3A	3	2	5	(3+5)=8	5	13	10	3
	4A	3	1	4	(3+6)=9	6	15	12	3
	5A	3	2	5	(3+6)=9	6	15	12	3
	6A	2	1	3	(3+5)=8	5	13	10	3
	7A	3	2	5	(3+6)=9	6	15	12	3
	8A	3	1	4	(3+6)=9	6	15	12	3
Side C	1C	3	1	4	(3+5)=8	6	15	10	3
	2C	3	2	5	(3+6)=9	6	15	12	3
	3C	2	1	3	(3+6)=9	5	13	12	3
	4C	3	2	5	(3+6)=9	6	15	12	3
	5C	3	1	4	(3+6)=9	6	15	12	3
	6C	3	2	5	(3+5)=8	5	13	10	3
	7C	3	1	4	(3+6)=9	6	15	12	3
	8C	3	2	5	(3+6)=9	6	15	12	3
Side C B-Layer	1CBL			2	4	4	8	4	
	2CBL			3	6	6	12	6	
	3CBL			3	6	6	12	6	
	4CBL			3	6	6	12	6	

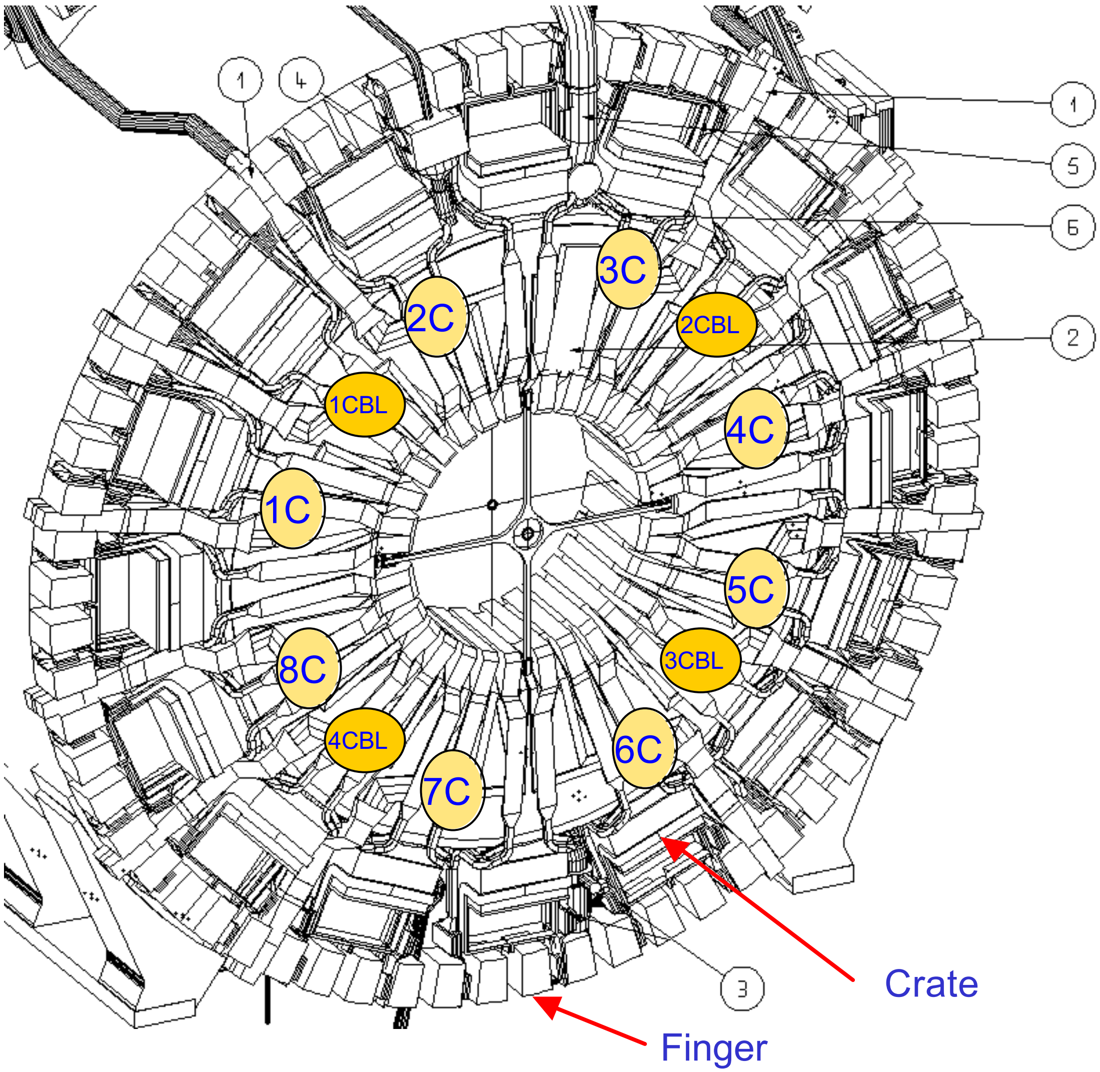


December 2000
Mechanics

Numbering scheme for each side looking
At IP from that side —position# coincides
Physically across ATLAS.

- Eight panels per side, plus four for B-layer, or 20 in total.

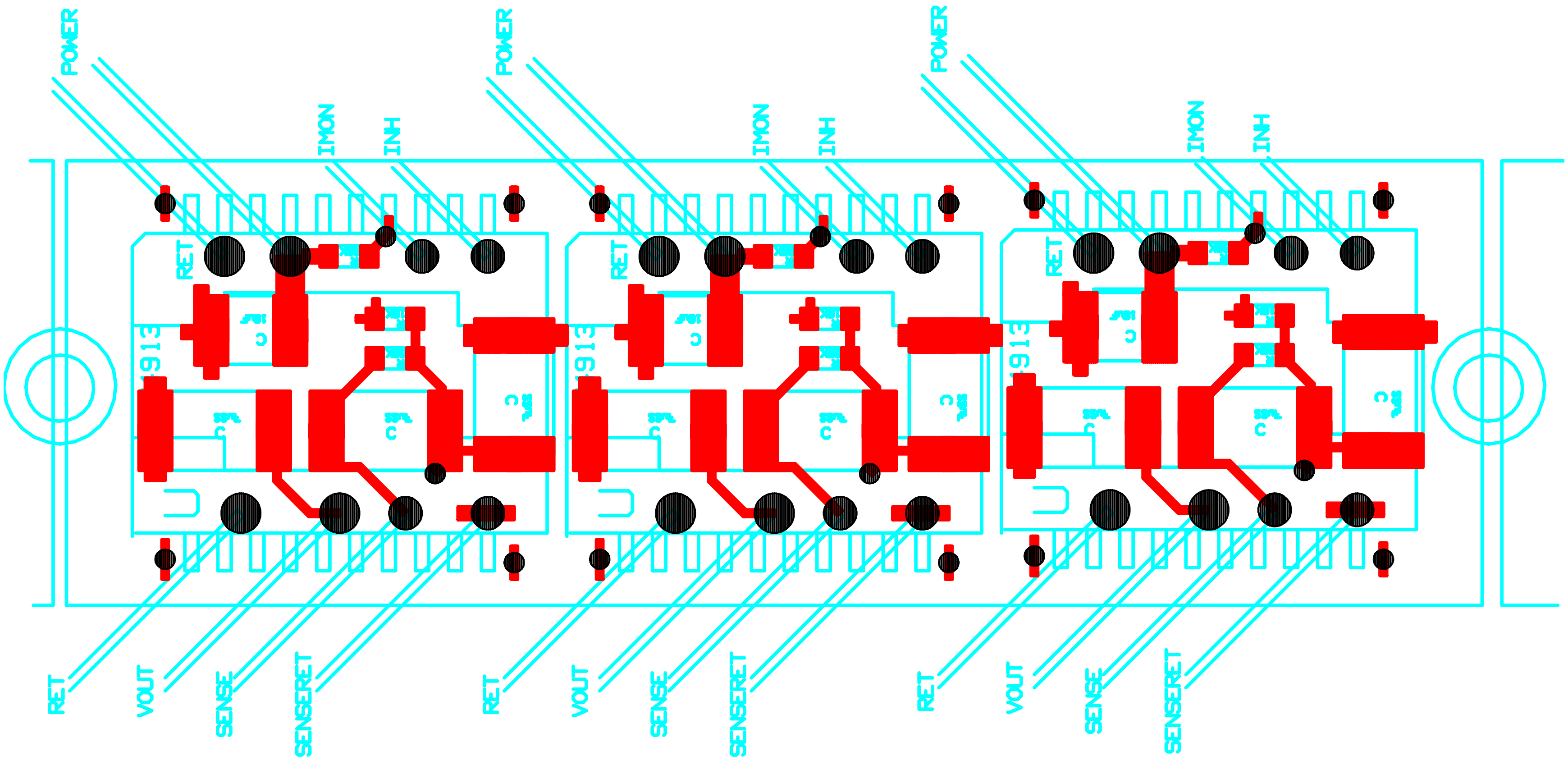
Location of PP2 boxes:



- Maximum of 15 bundles in one PP2, with nine 6-way and six 7-way bundles, for a total of 96 modules.
- If the 7-way ends up being 8-way for spares, total is 54+48 modules.
- Assume that we maintain at least a 1V drop across regulator to keep it regulating.
- This leads to a worst-case power dissipation, in the regulators alone, of 2W per module, or 200W for a PP2 box.

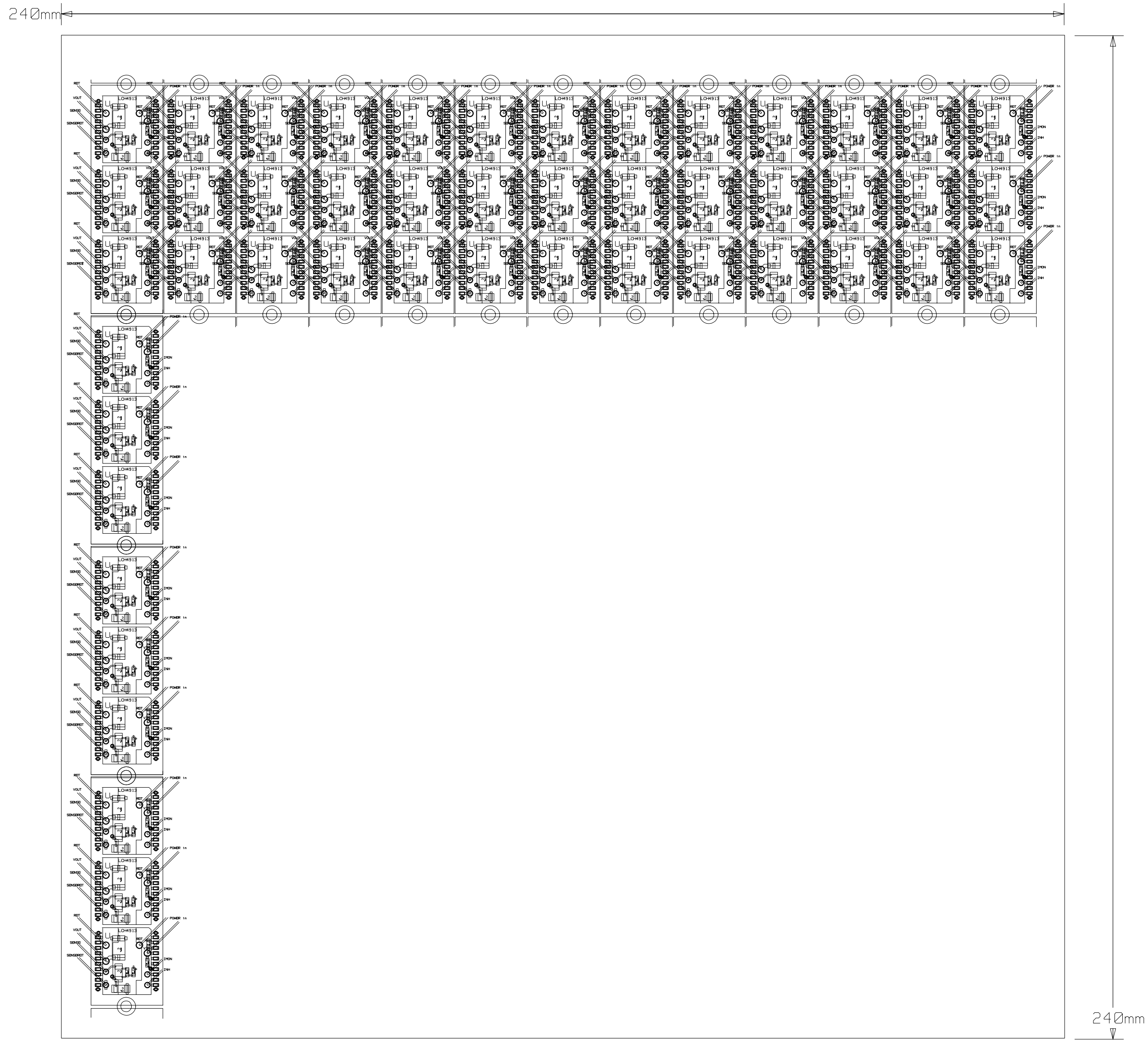
- Approximate size of a PP2 box is 280x280x50mm. The sides of the box will be covered with connectors for incoming Type 2 and outgoing Type 3 cables.

- Layout of “unit cell”, as shown in previous schematic, is repeated either two or three times to create a small board which provides all power required by module.



- The regulator is on the bottom of the card, and all passive components are on the top side of the card (red traces). All through-hole wire connections would also be made from the top side, under the regulator footprint.
- Individual cards would be screwed to both sides of cold plate, placing regulators in good thermal contact. Wiring harnesses would connect to box sides.
- The module size as drawn here is roughly 17x55mm, with layout above.

- Each of these module cards is electrically independent of all others in the box. They can then be arrayed 4x13 onto cold plate in the allowed space:

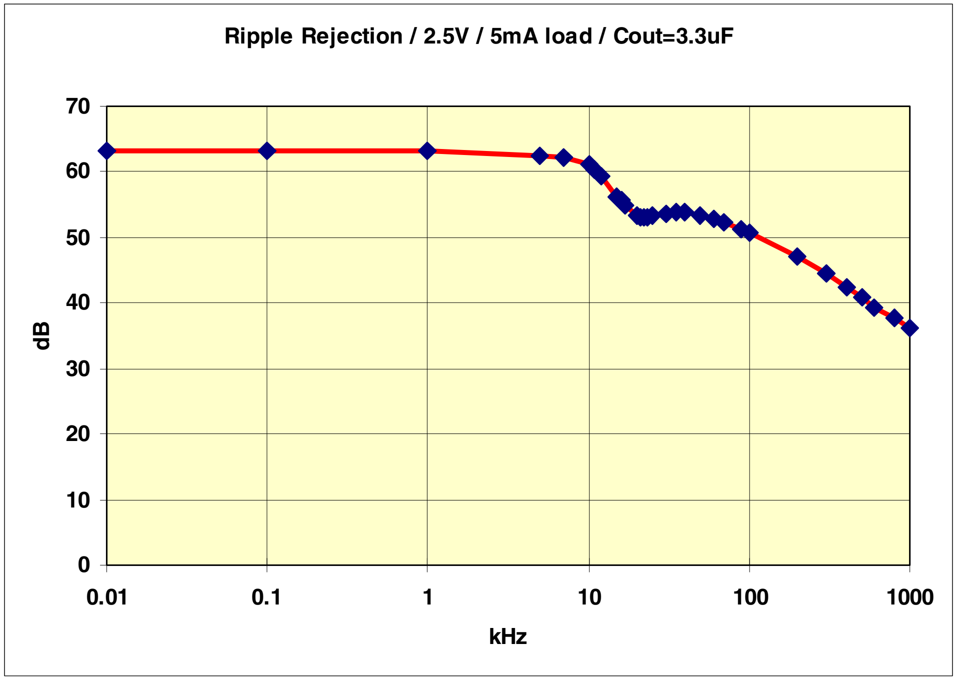


- Conclude: even for three supplies/module, the required components fit into box.

Advantages and Disadvantages of PP2 Regulators

Advantages:

- Location of linear regulator with good noise rejection relatively close to the pixel detector (7m) will provide much improved noise rejection:



- An AC sine wave noise component was applied to input, in addition to standard DC input.
- Roughly a factor of 1000 noise rejection (60 dB) was achieved over most of the frequency range.
- Higher frequency noise is well-controlled by decoupling capacitors.

- Regulator is implemented in 12V process, with Max input rating of 14V, so it will provide excellent transient protection against voltage transients on its input, severely reducing concerns about transient protection of modules themselves.

- The relatively high input voltage rating relaxes the major constraint on voltage drops from USA15 to PP2. Principle issue is to always retain the minimum drop-out voltage across the regulators (1V proposed here, which has at least 0.5V safety margin). The Type 4 cable could now easily have a 1-2V drop (assuming the large power dissipation can be handled), reducing its cost by a factor 4 or so (savings in the millions of CHF...)
- The remote sensing capability of the regulator is used to control the voltage directly on the module (assuming the necessary sense lines can be run to the end of the Pigtail, and bonded across to the power pads on the Flex3). This allows an automatic compensation for the expected drops of 600mV in the Pigtail, 500mV in the Type 1, and 150mV in the Type 2 cable. There is no need to carefully control the temperature of the low mass power cables in order to know their resistance. With the proposed decoupling on the ADJ pin, the regulator should be very stable.

Disadvantages, some specific to the LH4913:

- This new power system is not frequently accessible (requires “short move” access), and so reliability is a major issue. Every effort would need to be made to carefully engineer the system for reliability, and to burn-in all components. Given the independence of all channels, it is difficult to think of any “fail-safe” scheme short of doubling the number of regulators and keeping one set inhibited while the other is active.
- If one assumes a typical component reliability (MTBF) of 10^7 hours, then for the proposed system, there would be a failure of a regulator about every 100 days. This would cause the loss of operation of one pixel module.
- Such a sensing scheme can be dangerous in case of cable faults. However, if we always operate with a relatively low dropout voltage (necessary to control power dissipation !), then the regulators cannot generate any large voltage transients.
- ADJ control of regulator is not ideal for remote use such as proposed here. The control of the output voltage requires an adjustable resistor rather than a simple DAC input (voltage at ADJ must be referenced to voltage at SENSE). For use here, propose to use adjustable resistor on local board, and then modification of voltage set point would require access to PP2. Remote control would require custom rad-hard digitally-programmable resistor or opamp plus DAC.

- Concern about ramping performance, that is when the input voltage is ramped, does the output voltage ramp also, or is ramp capability lost ?

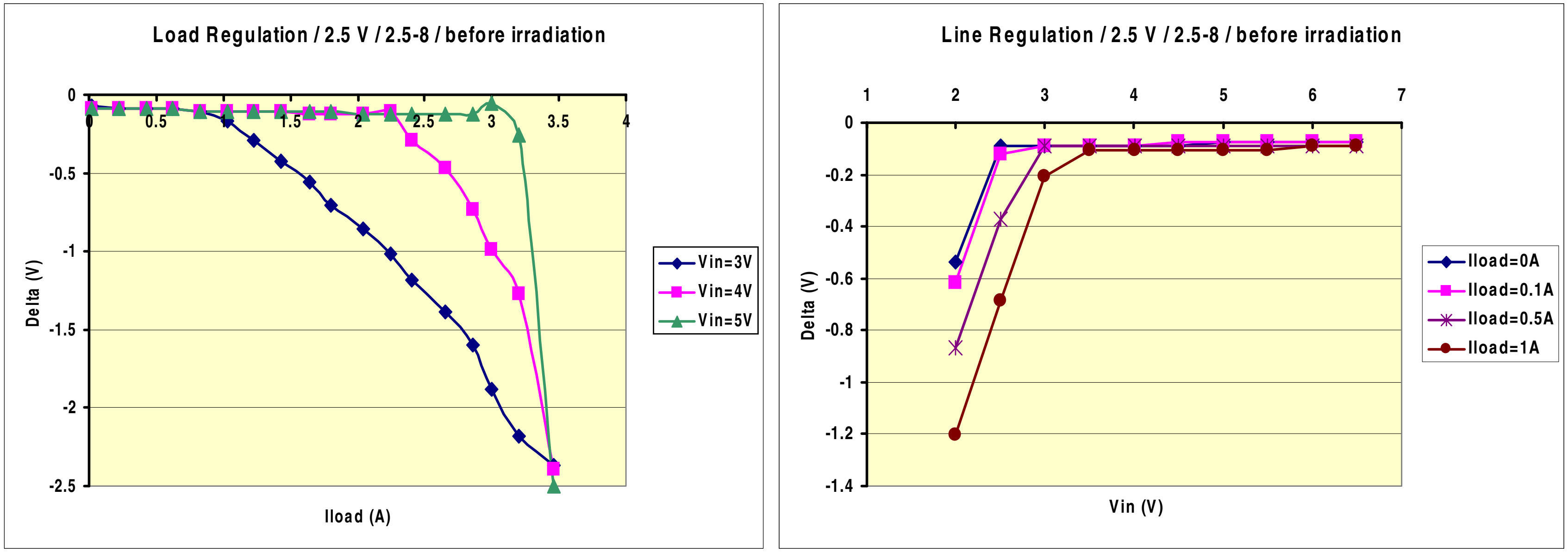


Fig. 6: Load (on the left) and line (on the right) regulation for a first edition chip, version 2.5 V.

- Design behaves like a resistor when input voltage is below drop-out voltage plus desired output voltage, so ramping behavior should be preserved almost unchanged.
- Present design, in which regulator behaves like a 3-terminal device (Sense_Return and Regulator_Gnd are identical) requires large currents to flow in Sense_Return, and these currents should increase as β of pass transistor degrades under irradiation (perhaps factor of 2 increase ?)

Services Implications

Major issue is remote sense operation.

- Had already planned to have sense wires running down to the Pigtail attachment point on the module. However, previous definition of sense lines was for monitoring purposes, and wire resistance was not constrained.
- L4913 regulator is a purely bipolar device, with very large bipolar acting as a pass transistor to regulate the output voltage. Since for a bipolar transistor, $I_C = \beta I_B$, one might expect about 1% of the load current to flow through the base (i.e. to appear as power consumed by the regulator). According to ST engineer, the current for operating this transistor is claimed to be about 40mA for loads of order 1A. It flows through the regulator ground ("sense return") out to the load, and then back on the VDD return. This requires that the sense return line resistance is only 1-2 ohms from PP2 to the load.
- For this reason, it is possible that the last part of the power distribution cabling, where space is most constrained, might not be fully included in the sense loop. This will be optimized over the coming months.
- Present plan has sense lines running back to PP3. This could allow location of regulators there if sensing over 25-30m loop proves feasible and reliability of regulator looks worse than expected. Otherwise, it would allow connection of these lines to DCS/ELMB for monitoring purposes.

Connection for baseline and regulator schemes

For baseline scheme (complex channels in USA15):

- The services are all modularity 1. This means that each pixel module has a full service bundle running back to USA15. The power supplies are modularity two, so each supply is connected to two bundles. In case one pixel module fails and must be turned off, one could remove that service bundle from the power supply, and revive the second pixel module.
- This means that one would always connect two modules within the same services bundle to ensure that no large ground loops are developed. This also means that all 7-module bundles in the barrel region would use 4 supply channels. The total for the detector would be 144 disk channels and 784 barrel channels instead of the 728 barrel channels one would naively calculate.
- Major issues for the modularity two scheme for supplies are generation of ground loops between two modules, and current monitoring for individual pixel modules.

For regulator scheme:

- Would propose to use the same power supply modularity as above as a default.
- Since the regulators are provided at the individual pixel module level, we have better control than for the baseline case (we can individually adjust or inhibit pixel modules) for the low voltages which are regulated (not for the detector bias).
- It would be possible to increase the power supply modularity to 4 instead of 2. This would mean that most channels would have 3 pixel modules per supply, so more of the maximum power capability would not (on average) be used. There would be 96 disk channels and 448 barrel channels. This would reduce the power supply module count, and match the modularity of the module level power supplies and the opto-card power supplies.
- In any case, the services modularity would be kept at 1. Given the large size of a pixel module in (η,ϕ) space, we strongly prefer a scheme where no more than one module would be killed by a power short condition. We also expect to upgrade the pixel system (certainly the B-layer) during the lifetime of ATLAS, and strongly wish to preserve more flexibility in supply modularity for the future. There seems to be little penalty in the overall service envelope for a change from modularity 1 to 2 (less than 10% overall).

Prototype Plans

- Presently have layout for a small three regulator board which can be inserted into a prototype power cable at the relevant place. This will allow us to evaluate this concept with our present rad-soft modules.
- Expect to repeat tests with “pre-production” version of regulator which should be delivered to CERN in April 2001.
- Next step in evaluation would be construction of a complete full-scale PP2 prototype (100 modules worth of regulators). Additional parts would be used for accelerated lifetime studies and reliability studies. This would take place in 2002.
- Finally, production could take place in 2003/2004 if we choose to proceed in this direction.